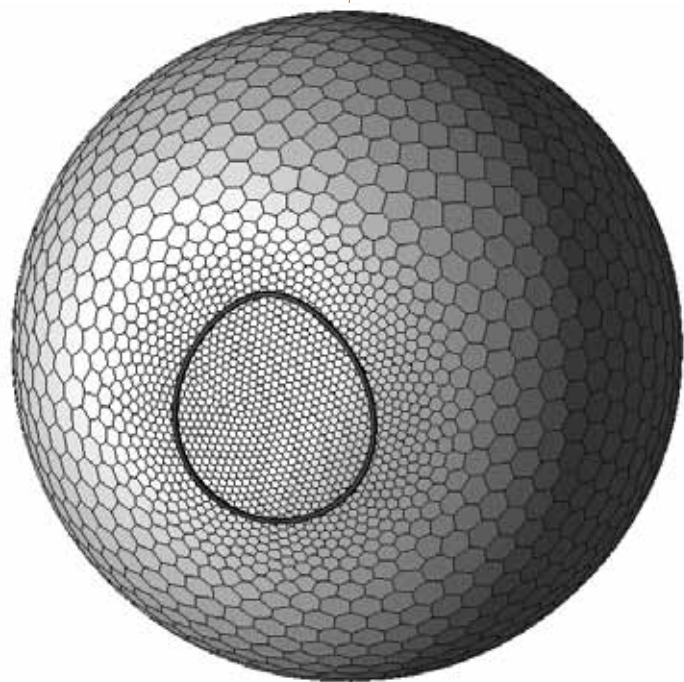


# Bridging Scales in the Earth's Climate System through Multiresolution Modeling

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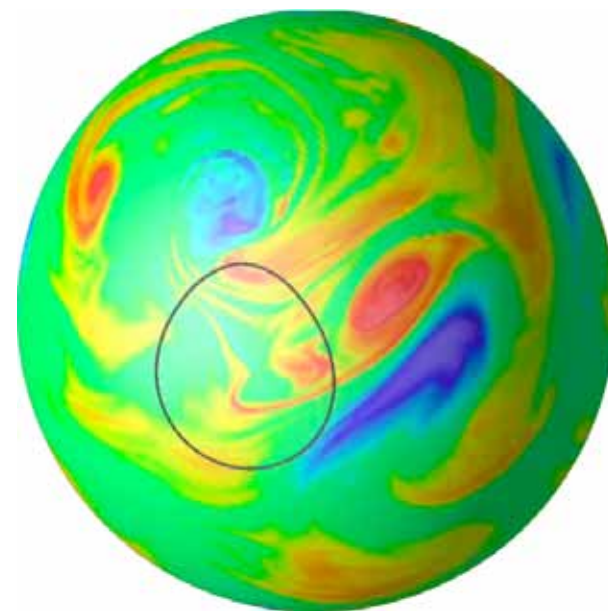
*Fig. 1. An example spherical centroidal Voronoi diagram [3]. In this simple example, the mesh is enhanced in a specific region of interest, in this case a topographical feature. Lower resolution is used elsewhere.*



In the coming decade and beyond, the climate modeling community will be challenged to resolve scales and processes that are far beyond its current scope. The challenge to resolve fine-scale and new processes will arise primarily for two reasons. First, unresolved processes that have a significant influence on the global climate system are likely to remain. Examples of such unresolved processes might include ice streams within large-scale ice sheets, ice shelves collapsing due to interaction with ocean processes, cloud processes in the atmosphere, and the dependence of ocean biochemistry on ocean

eddy activity. Second, there is the pressing need to quantitatively characterize the regional-scale signature of anthropogenic climate change. A regional example is the climate-change driven impacts to hydrological processes in the western United States.

The ability to resolve the scales noted above throughout the relevant climate system component is beyond the current computing capacity of even the most powerful computers available today. Basic scaling arguments of computer resources available into the future indicate that this situation will remain



*Fig. 2. Using a higher resolution version of the mesh shown in Fig. 1, a 2D turbulence simulation is conducted where the forcing is generated by an isolated topographic feature around which the mesh is enhanced. The field shown is relative vorticity. The simulation remains smooth even as strong filamentation occurs.*

for decades to come. As a result, the climate modeling community is faced with the challenge of creating numerical algorithms able to support multiple resolutions within a single global climate model simulation, where relevant processes are resolved in specific regions as opposed to being resolved globally. The creation of what is effectively a multiscale climate system model will allow the scientific community to explore the impacts of currently unresolved processes in specific geographic regions. Such a model will be of critical use to both society and policy makers in order to better understand the regional impacts of global climate change.

While it is clear that access to a multiscale climate system model would be of great benefit to both science and society, several fundamental challenges have precluded the creation of such a model to date. The first challenge is the creation of numerical algorithms

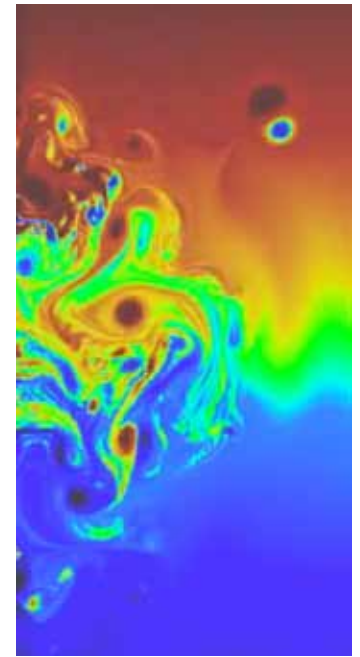
that can produce robust, stable simulations over century time-scale integrations when the resolution of the underlying grid varies substantially from one location to another. The second challenge is related to the physical parameterizations included in climate system models. In a climate model that supports multiple resolutions, physical parameterizations are required in low-resolution areas where direct simulation is not possible. Yet these same physical parameterizations must be excluded in high-resolution regions where the model is of sufficient resolution to directly simulate the phenomena. The creation of scale-aware physical parameterizations needed for climate system modeling has been elusive.

Along with our partners at the National Center for Atmospheric Research (NCAR) and Exeter University, the climate modeling group at LANL has made significant progress overcoming the first challenge listed above. Essentially, we have derived a finite-volume method that mimics the relevant aspects of the underlying equations of fluid motion, even when the method is situated on a mesh with multiple resolutions [1,2]. While the numerical algorithm is applicable to a wide class of meshes, it is most naturally paired with a spherical centroidal Voronoi diagram [3]. Figure 1 shows an example of a spherical centroidal Voronoi diagram where the surface of the sphere is decomposed into two dominate resolutions, with low-resolution covering most of the Earth and high-resolution used in the area of interest. When we use the multiresolution finite-volume method along with the mesh shown in Fig. 1, we find that we can simulate 2D turbulence without the need for ad hoc stabilization methods (see Fig. 2). In 2D turbulence, energy cascades upscale while potential enstrophy cascades downscale. Remarkably, the variable mesh simulation confirms our analytical findings that the discrete model conserves total energy to within time-truncation error, thus producing an essentially inviscid simulation. Over the next year the climate modeling group at LANL will create global atmosphere and ocean climate model components that can utilize this variable-mesh technology. The first steps toward this goal

have already been realized. Figure 3 shows a snapshot of potential vorticity for an eddy-resolving ocean basin simulation.

While a tremendous amount of effort is required before the full breadth of this approach can be realized, the idea has the potential to fundamentally change how global climate system models are used and developed. By allowing regions of local mesh refinement, our approach will enable new lines of scientific inquiry focused on climate processes with 1 km to 25 km length scales to begin decades before such resolutions will be resolved in traditional, globally-uniform climate system models. In essence, the approach will hopefully create a framework for the simulation of innovative, fine-scale climate processes within the context of global climate system modeling.

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**Fig. 3. A snapshot of potential vorticity from an idealized eddy-resolving ocean basin simulation.**

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